Historic, archived document

Do not assume content reflects current scientific knowledge, policies, or practices.

aS21
.A75U45
Cop 3

S

REVEGETATION OF LAND DISTURBED BY STRIP MINING OF COAL IN APPALACHIA

ARS-NE-71
AUGUST 1976

U.S. Department of Agriculture
National Agricultural Library
Division of Lending
Beltsville, Maryland 20705

AGRICULTURAL RESEARCH SERVICE • U.S. DEPARTMENT OF AGRICULTURE

Trade names are used in this publication solely for the purpose of providing specific information. Mention of a trade name does not constitute a guarantee or warranty of the product by the U.S. Department of Agriculture nor an endorsement by the Department over other products not mentioned.

This publication reports research involving pesticides. It does not contain recommendations for their use, nor does it imply that the uses discussed have been registered. All uses of pesticides must be registered by appropriate State and/or Federal agencies before they can be recommended.

CAUTION: Pesticides can be injurious to humans, domestic animals, desirable plants, and fish or other wildlife--if they are not handled or applied properly. Use all pesticides selectively and carefully. Follow recommended practices for the disposal of surplus pesticides and pesticide containers.

PREFACE

This report describes research to reveal and resolve problems associated with the revegetation of acid strip mine spoils of Southern Appalachia. Much of the research was conducted in West Va. It is part of a broad program of ARS research to reclaim disturbed lands in the United States.

The authors wish to thank Mr. James R. White, formerly associated with Ranger Fuel Corporation, for his cooperation and assistance; and the Texasgulf Inc., Aurora, North Carolina, for providing the phosphate rock.

The authors appreciate the assistance of Joseph O. Legg and George E. Griebel, Biological Waste Management and Soil Nitrogen Laboratory, Agricultural Research Service, in editing the manuscript.

CONTENTS

Page

BACKGROUND AND APPROACH TO PROBLEM..... 1
The Appalachian Region..... 3
States and areas..... 3
Past treatment of strip-mined spoils..... 3
Potential uses of strip-mine spoils..... 3
Economics of revegetation..... 4
Characteristics of Appalachian Acid Mine Spoils..... 4
Physical..... 4
Acidity..... 5
Plant nutrient problems..... 5
Development of Methods for Revegetation..... 6
Chemical analyses of spoil material..... 6
Greenhouse studies..... 6
Field experiments..... 7
Spoil Amendments Required for Revegetation..... 7
Neutralization of acid spoils..... 7
Limestone..... 7
Phosphate rock..... 7
Other amendments..... 8
Mulch Needed for Stand Establishment..... 8
Mulching materials..... 8
Pulp fiber..... 8
Straw..... 8
Sawdust..... 9
Woodchips..... 9
Cured hay..... 9
Chemical binding agents..... 9
In situ mulch..... 9
DATA FROM FIELD EXPERIMENTS..... 10
Spoil Amendments..... 10
Plant Species..... 11
Plant Growth Response..... 12
Spoil becomes Soil..... 17
Plant Species Evaluated for Fast Ground Cover, Spoil Stabilization, and Erosion Control..... 18
Weeping lovegrass and crownvetch..... 18
Bermudagrass..... 22
Blackwell switchgrass..... 25
Flat pea..... 26
Kura and Zigzag clovers..... 28
SPECIAL TECHNIQUES AND SEEDING PRACTICES..... 29
Lateral Groove Technique..... 29
Vegetative cover..... 31
Potential use of the lateral groove technique..... 35
CONCLUSIONS..... 37
LITERATURE CITED..... 38

REVEGETATION OF LAND DISTURBED BY STRIP MINING OF COAL IN APPALACHIA

By Walter H. Armiger, J. Nick Jones, and Orus L. Bennett[1/]

BACKGROUND AND APPROACH TO THE PROBLEM

U.S. history over the past 100 years has been marked by increasing population, growth in industrial and other economic activity, and ever-higher requirements for energy. Much of our need for energy is currently being met--and will probably continue to be met--from our considerable reserves of coal. The mining of coal for electric power production has been increasing at an especially rapid rate during the past decade. With the increasing price of oil, the demand for coal is expected to more than double by 1980. According to the U.S. Bureau of Mines, strip mining produced 276.3 million tons of coal in 1971, compared with 275.9 million tons from underground (deep) mines.

By 1971, the strip mining industry had disturbed approximately 3 million acres of land in the United States, of which slightly less than 1.5 million acres had been properly reclaimed. Strip mining of bituminous coal has affected 31 States, with resulting acres of land disturbed ranging from a low of 10 acres in Idaho to a high of 247,000 acres in Pennsylvania (7)[2/]. In Appalachia alone, 952,000 acres of land have been disturbed by strip mining for bituminous coal. Of this total acreage, 477,000 acres have been revegetated to a sufficient degree to be classified as reclaimed (7).

Strip mining for coal has caused nationwide concern not only because it has resulted in unsightly and barren "orphan" lands, but also because it has been accompanied by sedimentation and water pollution problems. In the Eastern United States, and especially in Appalachia, these problems occur as a result of mountainous terrain and high erodability and because of acidity of the spoil (land) material. In the absence of strict State and Federal revegetation requirements, serious erosion and pollution problems will continue to exist.

Some strip-mine spoils of the Appalachian region offer an extremely unfavorable environment for seed germination and subsequent plant growth. Without vegetative cover on these denuded areas, erosion will continue to be a serious problem, and acid water and sediment will remain two major sources of pollution.

1/ Research agronomist, agricultural engineer, and supervisory soil scientist, Northeastern Region, Agricultural Research Service, U.S. Dept. of Agr., Beltsville, Md., Blacksburg, Va., and Morgantown, West Virginia, respectively.

2/ Underscored figures in parentheses refer to Literature Cited at end of this publication.

A study conducted on the North Branch of the Potomac River from March to May of 1969 showed that acid mine drainage was destroying all forms of aquatic life in more than 40 miles of the River and in more than 100 miles of the tributary streams (3). Approximately 79,000 pounds per day of sulfuric acid were being emptied into the Potomac by West Virginia streams and approximately 39,000 pounds per day by the streams of Maryland. These estimates are based on the total acid content of the North Branch of the Potomac River at Beryl, W. Va. This location has a watershed of 287 square miles but the acid comes from only 20.6 square miles. The study points out the importance of revegetating strip-mine spoils as soon as possible in order to reduce erosion and runoff and the need to treat acid water discharged from strip and deep mines to minimize pollution of surrounding areas.

Before an intelligent attempt can be made to revegetate the acid areas of Appalachia, the problems associated with revegetation, both chemical and physical, must be identified. Many spoils are almost completely infertile and require applications of several nutrient elements for plant growth. In addition to the problem of low fertility, the spoil may also have the problem of containing iron, aluminum, zinc, and manganese in a low-pH environment which facilitates uptake of the elements by the plant in toxic quantities.

Other strip mining areas of the United States are confronted with different revegetation problems than those in Appalachia. In the West, the lignite coal-producing areas in western North Dakota are characterized by a geological formation consisting of alternating beds of lignite, shale, and sandstone. The spoil material there is more alkaline than the topsoil, but contains sufficient sodium to lead to a serious problem when revegetation is attempted. The

Figure 1. Results of a surface mining operation showing an area in great need of vegetation.

high salt content of the spoil material causes the spoil to crust and to be highly impermeable to water. Wyoming, for example, has very large reserves of coal (subbituminous), but revegetation is a serious problem because annual rainfall averages only 10 to 12 inches.

THE APPALACHIAN REGION

States and Areas

Appalachia includes 373 counties in Alabama, Georgia, Kentucky, Maryland, New York, North Carolina, Ohio, South Carolina, Tennessee, Virginia, and West Virginia. Georgia has only 40 acres of land disturbed by strip mining for coal and New York, North Carolina, and South Carolina do not strip mine any coal.

Past Treatment of Strip-Mine Spoils

The classification of past strip-mined spoils is a highly controversial topic in Appalachia. According to a 1974 study by the U.S. Department of Interior (2), the term "reclaimed" is not clearly defined, and variation occurs in its definition from state to state. Areas may be reclaimed under a state law and be legally considered reclaimed while at the same time being judged by other criteria as only partly restored. Reclamation standards frequently change with the advent of new knowledge gained through research. Land judged restored in 1 year might be considered only partly restored if evaluated by new standards at a later time.

Several surface grading techniques have been introduced to reduce sedimentation, but with only partial success. At many sites, trees, shrubs, grasses, and legumes have been planted, but their survival has been hindered by climatic factors, acidity of spoil material, and improper selection of vegetation. Black locust trees have grown to advantage in some plantings. Many areas have been planted with slow-growing conifers, which normally require 5 to 8 years to establish themselves satisfactorily. Numerous areas that have been planted to trees only were found to be inadequately restored or stabilized (2).

Reclamation in the mountainous regions of Appalachia will not be fully effective until more techniques become available in regrading, surface shaping, and seeding for (1) stabilization and erosion control and (2) economic utilization of the reclaimed land. A survey of past reclamation efforts indicates the need for a comprehensive research program that will include less destructive mining methods as well as improved selection of spoil amendments and plant species.

Potential Uses of Strip-Mine Spoils

Strip-mine spoils which have been reclaimed since 1972 and those that will result from future strip mining operations will have much broader use potential than those mined before 1972. The former wasteland sites have in some instances been made into recreation areas. Through preplanning and proper reclamation practices, forage grasses and legumes can be established which will provide cover, control erosion and sedimentation, and offer some economic

potential for the landowners. If reforestation is the goal, trees can be planted after grasses and legumes have grown for several years to effect spoil stabilization. In mountainous terrain, the bench areas and gentle slopes derived from strip mining offer a challenge for future use.

Production capabilities of many strip-mine spoils are at present not fully known or understood. Utilization, management, and wise use will need to be practiced in many strip-mine areas before the full potential of these man-made lands is reached. Location and accessibility will determine industrial and urban development and, in most cases, potential for recreation areas.

Economics of Revegetation

The economics of revegetation should be considered on a broad basis. Preplanning to integrate total reclamation costs will be geared to compliance with existing surface mining laws and regulations. However, if preplanning goes beyond stabilization *per se* and the alternate land use is given consideration, then backfilling, grading, seedbed preparation, applying soil amendments, species selection, seeding, mulching, management, and so forth may entail additional costs over and above those required to comply with current laws. Total reclamation costs, depending on conditions of the terrain may range from $50 to $5,000 per acre to keep erosion and sedimentation at a minimum and at the same time prevent overall environmental degradation.

The contribution which reclaimed strip-mine areas may make to our national life should not be underestimated. Through education and proper communication, these land areas disturbed by man should be given national importance. Restoration of the mined areas must go beyond restoring the aesthetic beauty to a planned alternate land use. The revegetated areas will enhance special-land-use objectives, such as recreational areas and commercial sites for industrial use, which should contribute to the economic growth of the region. The population of the Appalachian States has been slowly declining; but, as pressure for more living space increases, there may be a migration towards the less densely populated Appalachian region (10). Naturally, if this shift in population takes place, an increase in surface land values will follow the trend, offering increased diversification and economic justification for reclamation expenditures.

CHARACTERISTICS OF APPALACHIAN ACID MINE SPOILS

Physical

Recovery of coal by strip mine operations removes the protective vegetative cover and usually mixes the topsoil, subsoil, and rock fragments from the substrata into a heterogeneous mass. In Appalachia, approximately two-thirds of the soil material is finer textured than sandy loam and one-third is of coarse-textured material and large rock fragments. Because of these characteristics vegetative cover is difficult to establish (10).

Contour stripping is one of the main surface mining methods used in Appalachia because of the steep and rugged topography. The coal seams occur in approximately horizontal strata, usually less than 4 feet thick. Several of

these seams occur one above the other and are separated by intervening layers of rock. The coal is uncovered at the point where the coal seam surfaces on the mountainside. Such contour strip mining method leaves narrow bench terraces along the mountainside with a highwall and outslope. The outslopes usually contain loose and unstable material likely to become involved in massive slides and sheet erosion, the latter contributing greatly to sedimentation and pollution of streams. These are the problem areas that need stabilizing and revegetating as soon as possible after completion of mining operations. If such areas are allowed to continually erode, new surfaces and toxic materials will be exposed to weathering, thus creating toxic chemical reactions (10).

The spoil material can be considered as parent material just beginning the normal processes of soil formation. It is practically devoid of organic matter and thus no water-stable aggregates exist. Most spoil material has a tendency to form a crust on the surface and becomes very droughty during summer months. Because of these conditions, many strip-mine spoil areas will not revegetate satisfactorily by nature for many years even if primary-invader-type species are present around the disturbed area.

Acidity

The high sulfur-bearing pyritic roof coals and black shales located in the parent rock material cause the extremely low pH (2.4-3.0) found in some areas of Appalachia. The pyritic rock material, when exposed to weathering, oxidizes to form sulfuric acid. The spoil material in many instances contains large concentrations of Fe, Mn, Cu, Al, and SO_4 along with small amounts of needed plant nutrients, N, P, K, Mg, and Ca (1). This chemical composition of the spoil contributes to an environment under which it is difficult to establish vegetative cover.

Exposed sulfide minerals on the pyritic mine spoils oxidize to sulfates that are soluble and acidic. When water comes in contact with these minerals, the component salts are dissolved and the sulfuric acid formed further dissolves other minerals containing manganese, aluminum, and calcium (1). Pollution occurs when these dissolved and suspended materials are picked up in runoff waters to the extent that excessive amounts of acidity and iron can react with other constituents to produce toxic sediments in streambeds. This problem increases the need for vegetative cover on the strip-mine areas of Appalachia to minimize erosion hazards.

Plant Nutrient Problems

The problem spoils of Appalachia are extremely low in most of the plant nutrient elements essential for plant growth, specifically nitrogen, phosphorus, calcium, magnesium, and to a lesser extent, potassium. These deficiencies may be easily detected by conventional chemical analyses of the spoil material. The deficiencies of some essential plant nutrients are often accompained by excess of other elements that can be toxic to plant life. Therefore, it is important to select spoil amendment materials that will supply plant nutrients and also neutralize the toxic elements present in the spoil. One of

the more important nutrient elements essential for the growth of grass species is nitrogen. Since there is a continual need for this plant nutrient, an economic source of supply is essential.

Plant (symbiotic) nitrogen fixation is an economic source of nitrogen. Maintenance costs after revegetating acid mine spoils could be materially reduced if legumes could be established under strip-mine spoil environments to make use of symbiotic nitrogen fixation to supply the nitrogen needs of plants. Utilizing a rhizobium inoculant is satisfactory as long as the spoil acidity remains at pH 4.5 and above. But, because many spoils in Appalachia have a pH lower than 4.0, poor nodulation may result (8). Characteristically, the strip-mine spoils of Appalachia are practically devoid of organic matter which adds to the difficulty of securing survival of plant (symbiotic) bacteria.

DEVELOPMENT OF METHODS FOR REVEGETATION

Chemical Analyses of Spoil Material

In a revegetation program the chemical characteristics of the strip-mine spoil is determined. A chemical analysis of the spoil material will establish the presence of toxic elements that have to be neutralized. The analyses identify the needed plant nutrients essential for plant growth.

Strip-mine spoils vary greatly in chemical composition and often require markedly different reclamation and revegetation procedures to alleviate the toxic conditions. Once the composition of the spoil material has been established, then amendments may be selected that, in theory, should modify the spoil medium so that plant species may establish and survive.

In the laboratory, neutralization of the spoil material may be developed through equilibration studies. Selected amendments are added to neutralize the spoil to a predetermined equilibrium that is necessary for the growth of certain selected plant species. With this information, research conducted under greenhouse culture will provide preliminary tests of plant growth response of selected plant species to an amended acid mine spoil.

Greenhouse Studies

The information obtained from the chemical analyses of a particular strip-mine spoil dictates greenhouse studies. Amendments that have shown a favorable trend in the laboratory towards neutralizing the toxicity contained in a mine spoil are incorporated with the spoil material. Also, other plant nutrients needed for plant growth are added. Seed germination and early seedling development, under various treatments, are carefully documented for their tolerance to the amended spoil. Plant population density is another criterion by which to evaluate the importance of amendments added to correct the spoil toxicity.

To test or evaluate plant adaptation to the amended mine spoil under greenhouse culture is much more economical than to test the performance under the more expensive and complicated field trials. Plant species selected for greenhouse trials should be those that are known to be environmentally compatible in the region from which the spoil material was obtained and known to possess

such other characteristics as acid, drought, and heat tolerance. Many chemical aspects of plant development may be studied under greenhouse conditions that will contribute to saving time and money in developing a comprehensive research program under field conditions. However, physical properties, such as soil moisture relationships and effects of climate, must be evaluated on site for greatest relevance.

Field Experiments

Basic research conducted in the laboratory and greenhouse results in effective amendments and plant species that can be used for revegetation purposes on acid strip-mine spoils. An understanding of the principles involved in adapting spoil amendments and plant species to a particular environment increases the experiments's effectiveness in planning successful field studies. Field experiments under actual on-site environmental conditions are reliable sources of information that may be used to develop guidelines and recommendations for revegetation of strip-mine spoil in the area.

SPOIL AMENDMENTS REQUIRED FOR REVEGETATION

Neutralization of Acid Spoils

Limestone

Many of the strip-mine spoils of Appalachia are acid and need forms of limestone to neutralize this condition. The selection of the form of limestone to be applied is contingent upon the chemical analyses of the spoil material to be amended and economic availability of the limestone. Because a number of spoils in Appalachia lacked magnesium, an element essential to plant life, dolomite limestone (magnesium form) was selected as the lime amendment. On the acid mine spoils dolomite was almost as effective in raising the pH as was the calcite limestone. For instance, if the calcitic form raised the pH to 6.5, the dolomitic form would establish a pH of approximately 6.0 when both were applied at the same rate.

Phosphate Rock

In southern Appalachia the parent rock material of strip-mine areas, in most instances, is sandstone containing pyritic materials; the latter produce sulfuric acid when exposed to weathering. It was thought that raw phosphate rock would be a good spoil amendment for plant growth under the toxic pH conditions encountered in these spoils (pH ranging from 3.5 to 4.5). Phosphate rock contains approximately 30 percent total phosphorus with only 4 percent available in its natural state. However, phosphate rock is used in the fertilizer trade to produce superphosphate when treated with mineral acids. The acids convert the phosphorus to a readily available form for plant consumption. Also phosphate rock contains 48 percent calcium oxide (CaO) and 0.5 percent magnesium. The acid in the spoil will react with the phosphate rock to release some of the components (namely, phosphorus, calcium, and magnesium) necessary to support plant life.

When both phosphate rock and lime are added to a spoil, caution must be exercised in the rate of applying limestone. The pH should not be above 4.5 or the effectiveness of the phosphate rock will be restricted as the spoil will not be acid enough to acidulate the rock material.

Other Amendments

In most instances the nitrogen content of the spoils is extremely low and supplementary nitrogen must be added if successful vegetation is to be established. Some spoils contain sufficient potassium for plant growth, while in other spoils potassium must be added as part of the fertility program. Chemical analyses of the spoil material indicate when elemental deficiencies exist. Generally plant nutrient deficiencies become a major problem on most spoils, but instances occur in which certain nutrients from weathering rock are more abundant than in some undisturbed soils.

MULCH NEEDED FOR STAND ESTABLISHMENT

Mulching Materials

After backfilling and regrading, unless topsoil has been stockpiled and respread, the heterogeneous spoils possess little physical structure. Organic matter is generally nil so the spoils tend to crust after rain and dry out rapidly. Because of the exposure and dark color, the spoil may have a high surface temperature. Mulching materials are needed, therefore, to alter the surface microclimate and to help conserve soil moisture during the critical seedling establishment.

All of the organic materials studied were effective as mulches; the proper choice would depend upon cost and proximity of the source of supply to the area to be mulched. In our studies a number of available materials have been tested or observed.

Pulp Fiber

Many mine operators have been using pulp fiber (a waste material from pulp mills) as a mulch and applying it with a hydroseeder. Usually the seed, fertilizer, and pulp fiber are combined in the hydroseeder and applied in a single operation. To be moderately effective, the pulp fiber needs to be applied at the rate of 500 to 800 lb per acre. Because of its high cost pulp fiber is often applied too lightly or omitted except for seeding critical areas. Too light application of a mulch material on spoil reduces the effectiveness of the mulch, and, in many cases, results in no improvement in seed germination and ground cover.

Straw

Straw has been an effective mulch for new seedings on bare and untilled surfaces. Excellent seed germination has been obtained when 2 to 3 tons per acre of straw were distributed evenly over the spoil surface after seeding. Unchopped straw remains in place and is more effective, but manual labor is required for spreading on the spoil surface. Use of clean straw that is free

of weed seeds is important. When a straw mulch was utilized, there was no evidence of seeds failing to germinate. If the straw contains grain seed heads, a volunteer stand of grain may result. This may be advantageous as a nurse crop if the stand is not too thick.

Sawdust

In one test, sawdust proved to be a very good mulching material. The sawdust used was a well-weathered material that had been leached for at least a year. In another study the fresh sawdust used had a tendency to float or move when a high-intensity rain occurred. Several plant species were seeded in the first test and ladino clover seed germinated more prolifically from the use of sawdust than from straw or wood bark mulches. However, the use of sawdust will be limited by its availability in the surface mine reclamation areas.

Wood Chips

Wood chips are a satisfactory mulch for aiding seed germination because they remain in place, but they were not quite as good as straw mulch for establishing Ky 31 tall fescue or orchardgrass. Observations and results from other researchers indicate very favorable germination and seedling growth of certain clover and legume species when wood chips were used as a mulch. Bark and wood chips are very bulky and mechanical equipment for spreading is limited.

Cured Hay

Some mine operators are using cured hay as a mulching material with considerable success. Because some hay may contain sufficient grass seed, the hay serves both as a mulch and as a seed source.

Chemical Binding Agents

To provide erosion control and soil stabilization for seedling establishment many chemicals have been developed. When used alone, many of these chemicals do not satisfy the threefold purpose of a mulch; that is, to conserve moisture, moderate temperature, and provide soil stability. Some chemical binders used with organic mulches, such as straw or pulp have improved the stability of the mulch. For prolonged stabilization as needed during winter or drought periods, chemical binders enhance the mulch by improving stability through tacking straw to straw and straw to soil. However, data on suitability, availability, and cost of these binders are limited.

In situ Mulches

Research over the past several years has shown that an economical mulch can be produced in situ by seeding cereal grains or summer annuals, such as millet and buckwheat, as the first crop. Crops such as wheat, barley or rye are established without a mulch in the fall and are killed in the spring with herbicides before maturity, while summer annuals are killed by frost in the fall. The crop residues make a very satisfactory mulch for smaller seeded grasses and legumes which can be broadcast seeded without seedbed preparation

in the spring or fall. Experiments demonstrating the effectiveness of this system are described below.

DATA FROM FIELD EXPERIMENTS

On White Oak Mountain in southern West Virginia, a newly regraded surface mine site (Pocahontas #3 coal seam) was selected for an in situ mulch and variety study. In September 1970, wheat, barley, and rye were seeded, separately, with a conventional grain drill on a pH 3.8 to 4.0 spoil. At time of seeding, 600 lb per acre of a 10-10-10 fertilizer was drilled with the seed. No lime was applied at the time the cereal grains were established. Excellent fall establishment of the grains was obtained. Barley is very sensitive to high concentrations of aluminum and, seemingly, this toxicity curtailed plant vigor and some winterkilling of the plants took place.

Rye made the best growth of the three cereal grains. In May 1971, the block seeded to Abruzzi rye (Secale cereale) was killed by spraying with the herbicide, paraquat. The killed rye plants were utilized as an in situ mulch for the establishment of various clovers seeded alone and with a companion grass.

The experimental area was treated with a broadcast application of 3 tons per acre of dolomite, and 50, 105, and 120 lb per acre of N, P, K, respectively. The following legumes were broadcast seeded in the killed rye residue: Four varieties of red clover (Trifolium pratense L.), alsike clover (Trifolium hybridum L.), yellow sweet clover (Melilotus officinalis L.), and Emerald variety of crownvetch (Coronilla varia L.). For the companion grasses, Merion bluegrass (Poa pratensis L.), and creeping red fescue (Festuca rubra L.) were used with the three white clovers, and Ky 31 tall fescue (Festuca arundinacea L.) for all other grass-legume mixtures.

Excellent stands of the legumes and grasses were obtained by seeding into the in situ mulch. The seeding had been accomplished without any form of seedbed preparation. In addition to the in situ mulch, other factors that contributed to the successful stand were reduced soil water evaporation, rough spoil surface, and ample rainfall. Figure 2 shows an overall view of the experimental area 3-1/2 months after seeding of the grasses and legumes.

A number of experiments have been conducted over the past 5 years to determine which economically important grass and legume species may be suitable for growth under the adverse conditions encountered in Appalachia. One such study, which will be described in some detail, was designed to determined how plant species would be affected by spoil amendments on a newly regraded spoil bench area having a pH of 3.8 to 4.0. The mined coal seam was Pocahontas #3 located on White Oak Mountain at an elevation of 2,500 feet.

Spoil Amendments

A field experiment was performed in which 20 different combinations of fertility treatments were evaluated by 7 single-seeded grass and legume species and 3 grass-legume mixtures. The main objective was to determine spoil amendments best suited for spoil neutralization and for supplying the nutritive needs of forage plants at the same time. In addition, determining the effect

Figure 2. Left, growth of clover species 3-1/2 months after seeding. Rye killed with paraquat was utilized as an in situ mulch for seed germination and early seedling development.

of various spoil amendments on the persistence of plant stands or density was important. Major and minor spoil amendments considered in this study were dolomite, phosphate rock, superphosphate, potassium, molybdenum, and nitrogen.

The various fertility levels included different rates and combinations of phosphate rock, dolomite, superphosphate, potassium, and molybdenum. The entire experimental area received a blanket application of 50 lb N per acre at seeding and maintenance applications of 200 lb N per acre each spring. The phosphate rock, lime, superphosphate, and muriate of potash were applied with a 3-foot spreader. The nitrogen was applied with a conventional grain drill at seeding and surface broadcast each spring. All molybdenum treatments were applied in solution by using a standard garden sprayer. The fertility amendments were incorporated into the soil with a spring-tooth harrow. A Brillon seeder or cultipacker was used for the seeding of each single species and mixture with the exception of bromegrass, which had to be seeded by hand. The entire experimental area was mulched with straw to aid germination and early seedling development.

Plant Species

The grass species tested were: bromegrass (Bromus inermis), Ky 31 tall fescue, orchardgrass (Dactylis glomerata), and timothy (Phleum pratense). The perennial legume species were alfalfa (Medicago sativa) and ladino clover (Trifolium repens). Legume-grass mixtures seeded included alfalfa-bromegrass, and ladino clover-orchardgrass.

The annual legumes, crimson clover (Trifolium incarnatum) and hairy vetch (Vicia villosa), were included.

Plant Growth Response

The first cutting for yield data was made in July 1971. A second harvest was made in September 1971. The first two harvests indicated that Ky 31 tall fescue, orchardgrass, bromegrass, and timothy were all outstanding, with average yields of dry forage ranging from 10,300 lb per acre for the tall fescue to 7,500 for orchardgrass.

Figure 3 shows an overall view of the experimental area immediately following removal of yield samples for the second cutting of hay. Yield data are shown in table 1 for the plant species in the years 1971, 1972, 1973, and 1974, as affected by a selected group of the better spoil amendments. The productiveness of the species in the field followed trends obtained earlier in greenhouse studies designed to select spoil amendments that apparently neutralize or inactivate toxic elements in the mine spoil and at the same time furnish nutrients for plant growth.

Ky 31 tall fescue produces a heavy turf with an extensive root system and the species has a long growing season. Also, Ky 31 tall fescue is suited for areas where the fertility is low and moisture is limited at times during the growing season. Figure 4A shows the excellent growth of the tall fescue on spoil amended with 4 tons per acre of phosphate rock.

Figure 3.--Growth of grass and legume species at time of first harvest for yield data.

Table 1.--Annual dry forage yields of grasses for 1971-72-73-74 grown on the spoil fertility plots on White Oak Mountain, W. Va.

Spoil[1/] Amendments	Dry forage yields in tons per acre															
	Bromegrass				Orchardgrass				Ky 31 tall fescue				Timothy			
	1971	1972	1973	1974	1971	1972	1973	1974	1971	1972	1973	1974	1971	1972	1973	1974
P_2O_5 (super)	3.4	1.9	2.8	3.2	2.7	1.3	2.8	3.3	3.6	2.7	3.3	3.4	--	2.8	3.8	4.2
P_2O_5 (super) + K	1.8	1.6	2.5	3.2	2.5	1.5	3.3	2.8	2.9	2.5	3.2	3.3	--	2.2	3.8	3.8
P_2O_5 (super) + lime	3.0	1.8	2.8	3.4	3.0	1.5	2.3	3.0	3.7	2.6	3.2	3.7	--	2.2	3.3	4.1
Phosphate rock + K	2.7	2.0	3.1	3.9	3.1	1.7	3.2	3.7	3.9	2.7	4.0	3.9	--	2.6	4.2	4.7
Phosphate rock	2.7	1.7	2.8	4.5	2.9	1.6	3.7	3.7	3.8	2.8	4.0	4.6	--	2.6	4.7	4.9

1/ 50 lb of N per acre applied before seeding. Thereafter, 200 lb of N per acre was topdressed in the springs of 1972-73-74.

Bromegrass, a highly palatable, cool season, pasture or hay grass which is deep-rooted and rhizomatous, forms a heavy sod (fig. 4B). It is excellent in drought resistance, but its low yield is caused by rust.

Orchardgrass responds well to an application of 6 tons per acre of phosphate rock plus potash (fig. 4C). Less winter hardy than tall fescue or bromegrass, orchardgrass grows well into the fall, remains green, and is productive until freezing weather. The species is especially important because it is a quality forage.

Timothy, a bunch grass used primarily for hay, is grown in mixture with clover or alfalfa. The first harvest is for hay and the later aftergrowth may be pastured. Timothy makes better growth when it is seeded with a legume, probably benefiting from the extra nitrogen provided by the nitrogen-fixing legumes. Figure 4D shows excellent growth of timothy growing alone on a mine spoil.

Figure 4.--A, Excellent stand of Ky 31 tall fescue during its fourth growing season. B, Bromegrass showing good stand survival during its fourth year of growth. C, Lush growth of orchardgrass during its fourth season. D, Timothy provides good growth into its fourth year.

The early fall growth of alfalfa in the seeding year was promising, but winter heaving reduced the plant population by about 80 percent. By the end of the second season, the alfalfa had died out. Not only was the alfalfa affected by winter heaving, but the plant stand was further reduced by an attack of the alfalfa weevil. As a result of these problems, the survival of alfalfa in the grass-legume mixtures was very poor and the results recorded took into consideration only the survival of the grass species.

Another fertility study involving alfalfa was conducted on Bolt Mountain, W. Va., where the spoil pH was 3.2 and the site was at an elevation of 3,800 to 4,000 feet. Plants grown did not heave in winter and were not attacked by the alfalfa weevil. The plants persisted for 4 years and applications of dolomite and phosphorus were effective in promoting excellent plant growth (fig. 5).

Figure 5.--Views of alfalfa plots on Bolt Mountain. View on right, where amendments of dolomite and phosphorus were used, shows excellent growth. View on left, where no lime was applied, shows no growth; seeds failed to germinate. All plots received uniform applications of N and K.

Initially, ladino clover exhibited one of the most prolific plant stands of any of the species evaluated. Its lush growth is shown in figure 6. Deer and groundhogs showed a distinct preference for the white clover crop and grazed the ladino throughout the three seasons during which it persisted in the mixture. One important fact was established; ladino and other white clover varieties in adjacent experiments are preferred by wildlife over other plant species. This same trend of deer grazing has been observed by the author on research plots of ladino clover in western Maryland.

Crimson clover is tolerant of medium soil acidity. Valuable for winter grazing, crimson clover has become increasingly popular since the development of reseeding or volunteering varieties. It is an excellent plant for stabilizing a soil because it makes rapid fall seedling growth while forming a dense cover which prevents soil erosion during the winter months. The central taproot is supported by many fibrous roots. Crimson clover makes more growth at lower temperatures than most other clover species. It produces good quality hay that is high in nutritive value. The plants made excellent growth for the first season, but reseeding was negligible. The annual crop was very responsive to applications of dolomite.

Hairy vetch is winter hardy and will withstand below zero temperatures. It may be grown in practically all areas of the United States. Well adapted for soil improvement, its matting-type cover helps protect the soil from erosion. After its annual growth, the crop residue adds organic matter and improves the physical conditions of the spoil by adding plant food. Hairy vetch is

Figure 6.--Growth of ladino clover with some invasion by orchardgrass during the second year.

palatable to livestock and its feeding value is comparable with that of the clovers. Following its annual growth, seeds of timothy were broadcast into the sod of hairy vetch. The best fall growth was made by hairy vetch, but all plant species made what appeared to be good early growth. Figure 7 shows the early growth (fall 1970) of hairy vetch.

Spoil Becomes Soil

The amendment and plant species study on White Oak Mountain has shown that the acidity level of the spoil material has become well stabilized. Thus the spoil is starting the transition from spoil to soil. Spoil samples were taken before the study was established in the fall of 1970 and again in the spring of 1971. The results indicated that from fall to early spring the low acidity level had started to stabilize as follows: Fall of 1970, pH averaged 3.8 to 4.0. In the spring of 1971, lime plus superphosphate plots had an average pH 5.0, while phosphate rock, averaged 4.0. In the fall of 1973, the respective pH's were 5.8, and 5.4. Best plant growth responses were from plots amended with different rates of phosphate rock. Of unusual interest were the molybdenum treatments, which were applied at rate of 1 and 2 lbs per acre. It was presumed that the molybdenum would have its most positive affect, if any,

Figure 7.--Hairy vetch (right) provided the best early fall growth of all the plant species studied. Ladino clover-orchardgrass mixture and orchardgrass (left) are just becoming established under the straw mulch.

on the legume species, but the authors found that grass species were responding better to applications of molybdenum. This response has persisted for 4 years but has not been confirmed by other work.

Judicious utilization of spoil amendments is important in the production of economically important hay and pasture plants on an acid strip-mine spoil of southern Appalachia. The plant species are important as feed for livestock and wildlife and are excellent as spoil stabilizers. They offer good persistence and add much needed organic matter to the spoils. The longevity of the plant species, shown by their growth through four growing seasons, indicates excellent survival of many of the important species.

PLANT SPECIES EVALUATED FOR FAST GROUND COVER, SPOIL STABILIZATION, AND EROSION CONTROL

Weeping Lovegrass and Crownvetch

Weeping lovegrass (Eragrostis curvula) is considered a short-lived perennial. It does have some advantages as a plant species for strip-mine spoil revegetation: (1) rapid germination, (2) fast growth, (3) excellent root system, (4) tolerance of acid conditions, and (5) sod and aerial growth that provide a protective seedbed into which other more economically important plant species, such as crownvetch, may be seeded.

Crownvetch (Coronilla varia L.), (9) an excellent soil conserving plant and a long-lived perennial, spreads rapidly and grows well on eroded soils when supplied with lime and phosphorus. When properly managed, it is a good pasture plant.

A strip-mine area on White Oak Mountain, W. Va. was selected as a site on which to develop a research program that utilized phosphate rock to amend an acid mine spoil for the growth of weeping lovegrass and crownvetch. The site was characterized by an acidity index of pH 3.8 to 4.0 and was extremely low in all major plant nutrients. The site was considered a problem area because earlier attempts to revegetate with woody plants had been only partly successful. Chemical analyses of the spoil material indicated that it contained only 0.046 percent phosphorus and that aluminum was the predominant element present in toxic quantities.

Different spoil amendments of phosphate rock, superphosphate, and dolomite were used as variable treatments to correct the spoil toxicity and to furnish plant nutrients necessary to sustain plant growth and survival of weeping lovegrass and crownvetch plants. The main objective of the study was to evaluate the rapidity of germination and early growth of weeping lovegrass for quick ground cover and the importance of weeping lovegrass as a protective cover for the slower developing crownvetch. The experimental area received a uniform fertilization of nitrogen and potassium. All spoil amendments were broadcast and incorporated with the top 3 inches of spoil by rototilling. The weeping lovegrass and crownvetch were seeded June 6, 1970, and the experimental site straw mulched for germination and early seedling development.

While the germination of the lovegrass was rapid and excellent, only a few scattered plants of crownvetch initially germinated. The slow germination and early growth of crownvetch was expected as it is known to be slow during the seeding year. Excellent early growth of the lovegrass (5 weeks) is shown in figure 8A.

More plant growth response of weeping lovegrass occurred from application of 3,750 lb per acre of phosphate rock than from an application of 750 lb per acre of superphosphate. Both materials were supplied to give equal amounts of elemental phosphorus. Eight tons of dolomite per acre produced only a few scattered plants and was no better than the control. Lime (dolomite) plus phosphate rock added to the spoil resulted in depressed seed germination. The added lime reduced the spoil acidity which in turn restricted the solubilization of phosphate rock into available phosphorus.

Through the first season, the germination of crownvetch was extremely poor, with only a few scattered plants populating the entire experiment. The plant growth response of weeping lovegrass (3-1/2 months after seeding) is shown in figure 8B. The rapid growth indicates the value of this plant species for quick ground cover, an extremely important factor in a revegetation program. The rapid growth characteristic of the weeping lovegrass is shown by comparing figure 8A, with figure 8B.

During 1971 and 1972, the crownvetch population was increasing. By 1973, crownvetch was the dominant plant species. The plant growth response of crownvetch to treatments followed the same pattern as that shown by weeping lovegrass in the seeding year (1970). In 1974, the lovegrass had disappeared completely and crownvetch was the only plant species populating the experimental plots. The lush growth of crownvetch is shown in figure 9, during the fifth growing season. Data for the study are recorded in table 2.

This study indicated that weeping lovegrass is an important plant species for use in a revegetation program because of its rapid growth characteristic. Its sod furnishes a seedbed into which more economically important plant species may be seeded without further seedbed preparation. Also this study confirmed the value of phosphate rock as an amendment for acid mine spoils. Although the spoil contained toxic concentrations of aluminum, it was shown that the components of phosphate rock neutralized the aluminum and permitted normal plant growth. After a span of five growing seasons, the lush growth of crownvetch indicated that there was still residual phosphorus available for plant consumption from the initial application of phosphate rock made in June 1970.

Bolt Mountain

Some acid mine spoil areas of Bolt Mountain, W. Va., are characterized by acidity indexes that range from pH 2.4 to 3.2. An area with a pH of 2.8 was chosen an an experimental site. The spoil contained toxic concentrations of aluminum, but the phosphorus content was sufficient for vegetative growth of certain grasses. A chemical analysis of the spoil indicated the hostile environment could be altered with heavy applications of limestone. An equilibration study of the spoil material mixed with different rates of dolomite showed the degree of neutralization resulting from the applied amendment.

Figure 8.--Effect of spoil amendments on growth of weeping lovegrass: A, 5 weeks after seeding; B, 3½ months after seeding. All plots received uniform applications of N and K.

Figure 9.--Plant growth response of crownvetch to a single application of fertilizer, made 5 years previously. Weeping lovegrass had been used as the nurse crop.

Table 2.--Weeping lovegrass yields as influenced by applications of lime and phosphorus, White Oak Mountain, W. Va.

Treatment[1] (lb per acre)	Yield, lb per acre			
	1970	1971	1972	1971 pH's
No lime, no phosphorus	1,390	2,854	2,950[2]	3.52
3,750 phosphate rock	4,381	5,157	4,198	3.80
7,500 phosphate rock	4,162	4,510	3,742	4.15
750 superphosphate	3,700	4,510	4,198	3.45
1,500 superphosphate	3,629	4,630	3,526	3.08
16,000 dolomite	822	--	3,382	5.65
16,000 dolomite +3,750 phosphate rock	956	--	2,135	5.86
16,000 dolomite +7,500 phosphate rock	822	--	3,886	5.66
16,000 dolomite +750 superphosphate	4,064	3,742	3,718	5.67
16,000 dolomite +1,500 superphosphate	3,358	2,423	6,141	5.90

1/ 125 lb per acre of N and 100 lb per acre of K were applied to the experimental area as uniform amendments.

2/ Weeping lovegrass survival diminishing while crownvetch is becoming the dominant plant species.

The spoil treated with dolomite applied at 2, 4, 8, and 16 tons per acre had pH's of 3.4, 5.0, 5.3, and 5.9, respectively.

All plots were amended and seeded to weeping lovegrass on May 8, 1970; the photograph (fig. 10) which was taken on September 25, 1970, shows the plant growth during the seeding year. Excellent stands of grass were obtained at the 8- and 16-tons per acre dolomite rates. Early plant growth response was best at the 16-ton rate, but at the end of the first growing season the 8-ton per acre rate showed the best plant growth response of the variable rates.

Figure 10.--Foreground, no lime and 2 tons of dolomite per acre plots. Background, 4, 8, and 16 tons of dolomite per acre plots. All plots received uniform applications of N-P-K.

Bermudagrass

Bermudagrass is a promising grass species to be utilized on low pH strip-mine spoils wherever it is climatically adapted. Its tolerance to toxic mine spoil materials was shown through pot experiments conducted under greenhouse culture. Most strains of bermudagrass tolerate low pH and high concentrations of aluminum, iron, and manganese. Also, this deeprooted, fast growing, drought tolerant grass produces good quality forage (4).

Bermudagrass spreads by underground rhizomes and aboveground stolons and produces a dense sod with excellent erosion-control potential. The most economical means of propagating is by direct seeding; however, some of the more productive strains are sterile hybrids that must be propagated vegetatively by using rhizomes and stolons.

Bermudagrass strains native to Appalachia were collected and tested for their production and reseeding potential as well as for their ability to withstand low pH's and temperatures. In addition tufcote bermudagrass, a sterile hybrid, was tested under variable toxicity and climatic conditions. A field trial was conducted on Bolt Mountain (southern W. Va.) on a strip-mined spoil of extremely low pH (3.2). Several strains of bermudagrass, including tufcote, were grown to test the plant growth response and survival on a mine spoil amended with different rates of dolomite, phosphate rock, and nitrogen with a uniform application of potassium (2).

The bermudagrass was established by planting sprigs and plant runners and by direct seeding in June 1971. An excellent stand of the different plant species was obtained on all plots. The plants made lush growth during the summer and fall (fig. 11) and entered into winter season after one harvest in midsummer. Table 3 shows yield data for the years 1971-72-73-74. The plots were not harvested late in the season as it was theorized that a heavy cover of grass would afford a protective insulation for the spoil surface during the winter months. Bermudagrass propagates mainly by underground rhizomes. To maintain survival of these species, the underground rhizomes must be protected from freezing. To determine the effectiveness of this technique, two soil temperature probes were inserted into the spoil, one just beneath the surface and the other to a depth of 3 inches. Temperatures were recorded daily.

We found that when the air temperature reached -10° F the spoil surface had a 24° F reading for a short period of time. During most of the winter season, the spoil surface had temperatures that ranged from 37° to 43°. An on-site observation of the area was made during January 1972 on a day when the outside temperature was below freezing. The denuded area adjacent to the bermudagrass plots was frozen. The spoil surface under the bermudagrass was entirely unfrozen. The results of this test indicate that a southern grass may be adapted to colder climates under selected management practices.

Field trials near Morgantown, W. Va. tested the establishment and growth of midland and tufcote bermudagrasses on a strip-mine spoil of pH 3.2. The effect of varying rates of dolomite and phosphate rock were studied as spoil amendments to stabilize the acid mine spoil into a growth medium for the two strains of bermudagrass. Both strains of bermudagrass are sterile hybrids and are propagated by planting sprigs containing underground rhizomes. The two strains differ in that midland is a hay-type grass while tufcote is a lawn or pasture-type grass. In addition to the lime and phosphate rock variables, uniform applications of nitrogen and potassium were made. Three rates of dolomite, 2, 4, and 6 tons per acre and phosphate rock, 1-3/4 and 3-1/2 tons per acre were applied to the spoil. It was found that only relatively small amounts of lime (2 tons per acre) or phosphate rock (1-3/4 tons per acre) were needed to overcome the toxic effects of high concentrations of aluminum and manganese, and yet the pH of the spoil was not raised significantly by phosphate rock (3.2 to

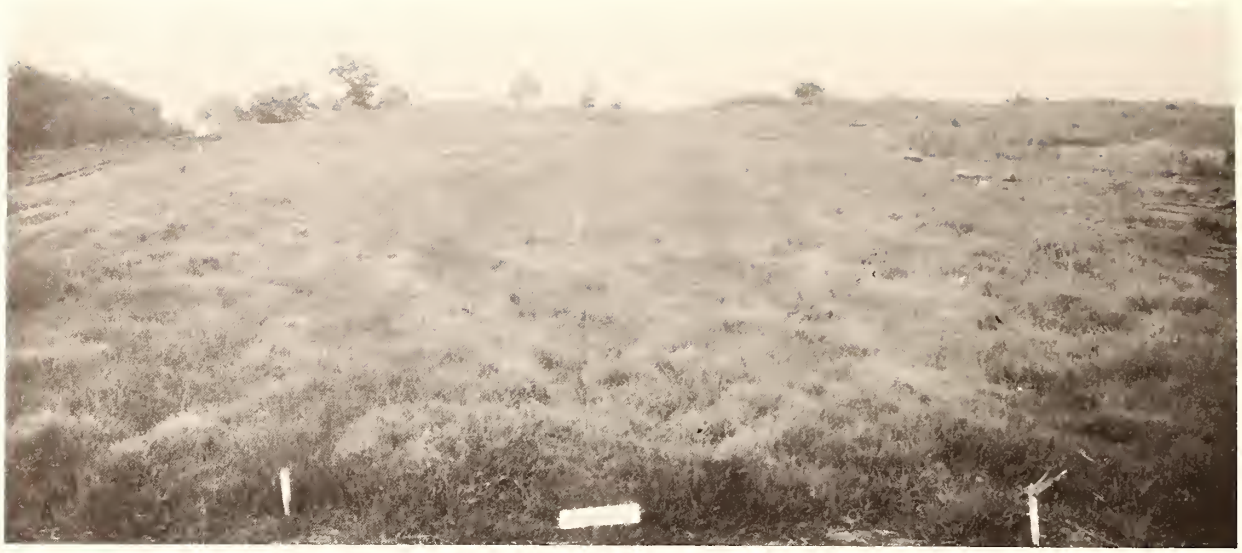

Figure 11.--Bermudagrass makes excellent growth on Bolt Mountain, W. Va.

Table 3.--Dry-matter yield data of bermudagrass at Bolt Mountain, W. Va.

Lime and phosphate treatments	Rates of nitrogen	Dry-matter yields			
		1971	1972	1973	1974
		Pounds per acre			
5 tons of dolomite + 80 lb P_2O_5	100	3,718	1,779	7,662	2,360
	200	4,622	3,882	10,381	7,183
	300	5,277	4,241	9,577	5,610
5 tons of dolomite + 160 lb P_2O_5	100	4,877	2,121	8,654	5,644
	200	7,004	4,891	10,842	8,004
	300	7,772	4,378	10,483	5,815
5 tons of dolomite + 320 lb P_2O_5	100	6,149	2,907	9,612	4,087
	200	8,219	4,943	8,517	4,618
	300	6,277	5,216	9,064	5,285
4 tons dolomite + 2 tons rock phosphate	100	4,670	3,301	8,124	5,781
	200	7,508	5,268	9,287	4,994
	300	4,446	5,541	10,586	5,233
2 tons dolomite + 6 tons rock phosphate	100	5,725	3,523	7,747	6,106
	200	7,324	5,456	9,389	8,551
	300	7,068	6,106	10,757	6,824

4.0). Two harvests of plant material were made in 1971; yield data are shown in table 4.

Table 4.--Dry-matter yield of midland and tufcote bermudagrass grown on low pH (3.2) strip-mine spoils at Morgantown, W. Va.

Treatment (tons per acre)		July 5, 1971		September 8, 1971		Total	
Lime	Phosphate	Midland	Tufcote	Midland	Tufcote	Midland	Tufcote
		Pounds per acre					
0	0	131	723	402	2,562	533	3,284
2	0	1,707	727	6,387	7,470	8,094	8,197
4	0	911	292	5,326	7,522	6,237	7,814
6	0	640	460	4,990	6,479	5,629	6,939
0	1-3/4	1,253	1,552	2,570	5,419	3,822	6,971
0	3-1/2	3,090	2,546	5,608	7,241	8,698	9,827

Blackwell Switchgrass

Switchgrass (Panicum virgatum) is a perennial, sod-forming grass which grows well in nearly all areas east of the Rocky Mountains. It is a coarse-stemmed, broad-leaved plant which spreads by short rhizomes and grows to a height of 3 to 5 feet. Most of its usage occurs in the Great Plains area. Good growth occurs on fertile soils that are well supplied with moisture. Switchgrass is widely used for hay, summer pasture, and erosion control. Although well adapted to moist fertile soils, it produces very good growth and cover on droughty, infertile, and eroded soils.

Blackwell switchgrass is a rust-resistant leafy strain that gives high forage yields. It is a superior grass to protect permanent waterways (4). If the Blackwell strain could tolerate the acid mine spoils of Appalachia, this would represent another good soil conserving plant species to help in revegetating this particular area.

Preliminary study was made with Blackwell switchgrass growing, under greenhouse culture, on a pH 2.8 mine spoil from the vicinity of Morgantown, W. Va. The switchgrass responded well when the spoil was amended with 4 tons per acre of phosphate rock and 2 tons of dolomite with a topdressing of 100 lbs per acre of nitrogen. The excellent plant growth response to the spoil amendments warranted the establishment of further studies under field environmental conditions.

An acid mine spoil (pH 3.2) located on Bolt Mountain, W. Va., was selected as a site on which to grow and evaluate switchgrass as a plant species for revegetating strip-mine spoils in Appalachia. Phosphate rock and dolomite were applied in combination at varying rates along with single treatments of 10 tons per acre of phosphate rock and 320 lb of P_2O from superphosphate plus 3 tons per acre of dolomite. Amendments were applied and Blackwell switchgrass

was seeded in the spring of 1971. Plant growth response to amendments under field conditions was excellent during the years 1972, 1973, and 1974 (table 5). Six tons per acre of phosphate rock plus 2 tons of dolomite yielded highest tonnage (15.8) for the 3 years. The superphosphate plus limestone treatment yielded the least (10.6). Ten tons per acre of phosphate rock was one of the best treatments. The phosphate rock plus lime treatments indicate that Blackwell switchgrass is a good plant species for growth on acid mine spoils for stabilization, ground cover, and yield potential.

Table 5.--Blackwell switchgrass yields on Bolt Mountain, W. Va.

Spoil amendments[1/] (per acre)	Yield in tons per acre			
	1972	1973	1974	Total
2 tons phosphate rock + 4 tons dolomite	3.9	5.3	6.2	15.4
4 tons phosphate rock + 3 tons dolomite	2.9	5.4	4.4	12.7
6 tons phosphate rock + 2 tons dolomite	3.8	6.9	5.1	15.8
10 tons phosphate rock	4.5	5.4	5.5	15.4
320 lb P_2O_5 (superphosphate) + 3 tons dolomite	1.6	4.1	4.9	10.6

1/ All plots amended with uniform application of N and K.

Flat Pea

Flat pea (Lathyrus sylvestris) is a long-lived, perennial, rhizomatous legume. A viny plant with tendril-bearing stems, flat pea usually forms a dense mat, making it valuable as a conservation plant. Primary use of flat pea would be to establish cover on critical outer slope areas, but it also has value as wildlife food and cover. To date, its value as a livestock feed is not fully known.

The extensive taproot system of the flat pea seemed to make it an ideal plant species to test for its spoil stabilization potential to heal tension cracks that develop along the border of the bench area and outer slope. These tension cracks are the forerunners of spoil slides on outer slopes that contribute to the erosion and sedimentation problems. Observation plots were located along the edge of the bench area and the outer slope of a site on Bolt Mountain that was characterized by a spoil pH of 2.8. The area was amended with phosphate

Figure 12.--Note the extensive taproot of the flat pea plant. The pencil on left points to nodule formation on roots.

Figure 13.--Flat pea growing over a tension crack between bench area and outer slope on Bolt Mountain. There has been no evidence of sloughing of spoil from the tension crack in the 3 years that flat pea has been growing.

rock,dolomite and nitrogen. The flat pea made excellent growth at this fertility level and developed a deep penetrating taproot. Figure 12 shows good development of the plant root system and figure 13 shows the vegetative growth over a tension crack.

During 1973, a prolonged period without precipitation showed that flat pea wilted badly from lack of moisture, but recovered and grew normally when rain finally fell, confirming that flat pea resists drought. By growing through four seasons this plant's survival has been excellent. This seems to be a very promising leguminous plant species for revegetation purposes on acid strip-mine spoils, but seed sources are limited.

Kura and Zigzag Clovers

Kura clover (Trifolium ambiguum) and zigzag clover (Trifolium medium) are two legumes about which very little is known. Kura clover, a leguminous species, has highly desirable agronomic qualities. It has exceptional ability to spread extensively by rhizomes, an important factor in establishing a perennial legume (6). It is resistant to some diseases, is extremely attractive to bees due to its nectar content. Its extensive root system makes it extremely valuable as a soil conserving plant. It has been said that kura clover is drought resistant, but can grow under conditions that are too wet for successful alfalfa production. Investigators in the United States were almost completely unaware of the species until 1941, when some seed from the Caucasus area was imported. After its introduction into the United States, kura was at a disadvantage for many years because there was no known rhizobium culture that would inoculate T. ambiguum. Thus the plant was unable to fix nitrogen. Only recently have cultures capable of producing active nodules on the roots been available in the United States.

Kura clover seems to possess properties that would make it a valuable leguminous plant species to be utilized in the revegetation of acid mine spoils of Appalachia. It is winter hardy, having persisted in Iowa, Wisconsin, other Northern States, and in Canada for a number of years. The establishment of kura clover depends upon a balanced fertility program. It is potentially a heavy seed producing crop, but the mature seeds shatter readily. This characteristic would make growing of kura valuable in an area where it is left to grow continuously without harvest. The first year kura is slow to produce a continous sod, but later it spreads and forms a dense sod by spreading vegetatively by underground rootstocks. This characteristic has been observed in the stripmine spoils of West Virginia.

Zigzag clover is a long-lived perennial with a rhizomatous root system (5). It was reported growing on dry hillsides in Massachusetts and in other parts of the country before 1860. Zigzag has shown an adaptation to the unglaciated sandstone shale soils of Indiana. These soils are water-logged in winter and very droughty in summer. The clover made exceptionally good growth in the spoils and was not affected by winter heaving. We have observed that it is compatible with tall fescue when grown in a mixture. The high degree of disease and insect resistance of zigzag clover accounts for its ability to survive for over half a century. The reason for its relative obscurity is low seed production.

Kura clover (5) and zigzag clover (6) were grown on White Oak Mountain (pH 3.8 to 4.0) and on Bolt Mountain (pH 2.8 to 3.2). In both areas the clovers responded to spoil amendments of dolomite and phosphate rock. The kura clover was inoculated with a rhizobium culture that had been isolated (at the Agricultural Research Center, Beltsville, Md.) and found to produce effective nodules. There has been no prior problem with procuring the rhizobium culture for zigzag clover. Seeding at the two sites was accomplished on May 4 and 5, 1971, respectively.

The growth of both clover species was excellent at each site and nodulation occurred on the roots of both species. Upon examination, the nodules were found to contain live bacteria. On the more acid spoil of Bolt Mountain, plant nodulation was not found below the surface 2 inches, the area in which the lime and phosphate rock had been incorporated. The nodules on plants from White Oak Mountain were not examined. The acidity index of the spoil profile was determined in the fall of 1974, at Bolt Mountain and found to be as follows: 0 to 3 inches, pH 6.4, 3 to 6 inches, pH 4.5, 6 to 9 inches, pH 3.9, and 9 to 12 inches, pH 3.7.

SPECIAL TECHNIQUES AND SEEDING PRACTICES

Stabilization of steep outer slopes against erosion continues to be one of the most complex problems associated with surface mine reclamation. Without vegetation the slopes are the main contributors to sedimentation and pollution of streams, often miles from the actual scene of mining operations. Unfortunately, water running down the long steep slopes results in erosion which destroys emerging vegetation and leaves permanent and growing scars. Figure 14 shows a badly eroded outer slope. The steeper slopes need special techniques and seeding practices to ensure germination and rapid early growth of selected plant species. Methods had to be devised that would hold seed and fertilizer in place until germination was established and protection afforded for seedling development. Retention of precipitation on the outer slope is necessary for the establishment and maintenance of vegetative cover.

In 1971, two mountain sites in southern West Virginia were selected for evaluation of techniques and seeding practices necessary to successfully vegetate steep outer slopes. An area on White Oak Mountain was characterized by an acidity index of pH 4.1, and the area on Bolt Mountain was extremely acid with a pH of 2.9. The slope percentage at each location was not accurately determined but exceeded 65 percent.

Lateral Groove Technique

In the experiments, a series of stairstep terraces (grooves) were constructed with hand tools on the steep outer slopes of each experimental site. The terraces were spaced 18 to 24 inches apart down the slope, on the contour and parallel to the main bench. A schematic drawing illustrates this technique, (figure 15); it was used with experimental plantings for vegetative cover. The miniature terraces provide ledges for holding water, seed, fertilizer, and lime, improve the microclimate for germination, and help develop deep, penetrating plant root systems. Water retention through soil infiltration on slopes is necessary for establishing and maintaining vegetative clover.

Figure 14.--Badly eroded steep outer slope, a source of sedimentation and pollution problems.

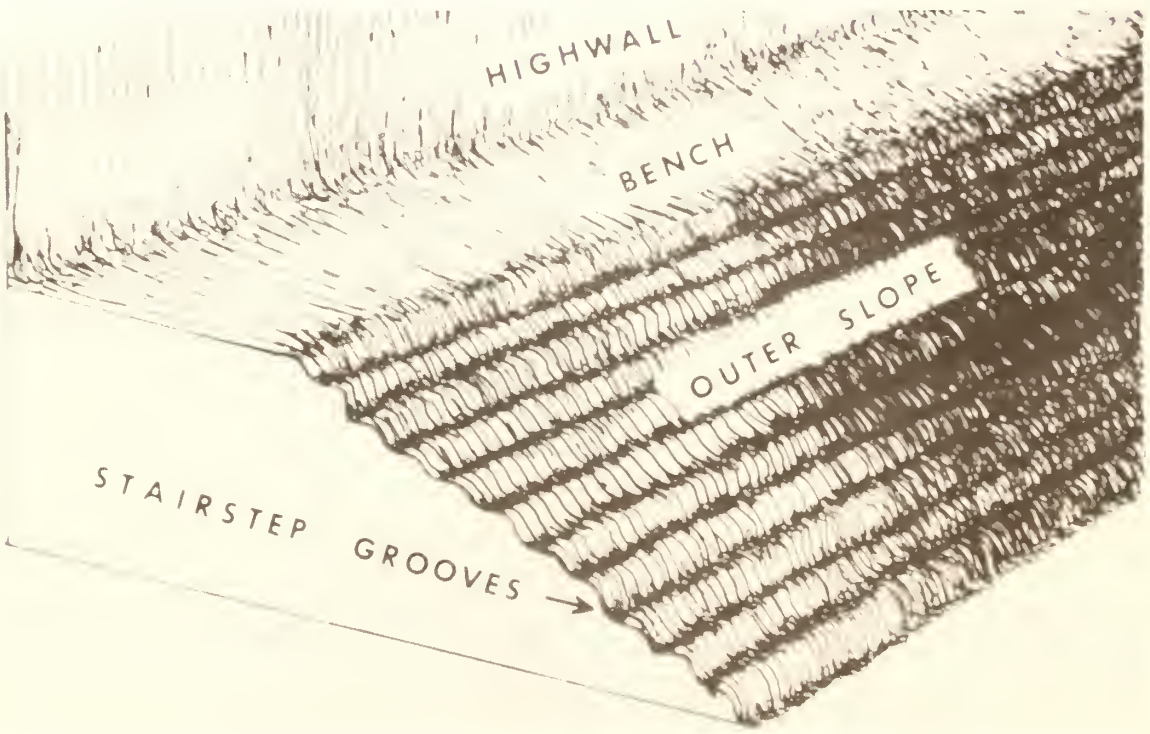

Figure 15.--Schematic drawing of outer slope configuration showing utilization of the stairstep groove technique.

On the more acid spoil at Bolt Mountain, 5 tons per acre of dolomite were applied uniformly to the experimental area and at White Oak Mountain, 2 tons per acre were applied. Other spoil amendments, uniformly applied at both locations, included 50 lb per acre of nitrogen, 150 lb of potassium, and 1 lb of molybdenum. The variable spoil amendment treatments utilized at both locations included 2, 4, and 6 tons per acre of phosphate rock and a single application of superphosphate, comparable in phosphorus content to 4 tons per acre of phosphate rock.

At both locations the experiments were conducted on a split-plot design with three replicates. In the main treatments, three rates of rock phosphate were compared with superphosphate in 9- by 28-foot plots (table 1). The plot widths were located at the top of the slope, and the length extended down the slope from the bench. Each plot was divided (9 feet by 14 feet) and randomly seeded to a special legume either directly or by transplanted greenhouse grown seedlings spaced about 18 inches apart on the stairstep terraces. Birdsfoot trefoil variety 'Empire' was used at White Oak Mountain and crownvetch variety 'Penngift' at Bolt Mountain. The entire area of each of the experiments was overseeded with weeping lovegrass to provide quick cover and stabilization.

Vegetative Cover

The handset birdsfoot trefoil plants made excellent growth at White Oak Mountain. Germination and subsequent plant development on the seeded plots were also very good. Results of seedling establishment and early growth are shown in figure 16. Weeping lovegrass and birdsfoot trefoil became established in the grooves and appeared to shade and otherwise protect the steeper slopes, and full vegetative cover by late summer (figure 17) gave excellent erosion control.

Complete ground cover was obtained on both experiments at Bolt Mountain. However, weeping lovegrass made up more than 75 percent of the cover during the seeding year. Transplanted crownvetch plants made satisfactory growth with all four fertility treatments. Figure 18 shows the plant growth response of weeping lovegrass and crownvetch to an application of 320 lb of P_2O_5 per acre from superphosphate.

The initial growth from direct seeding of the special legumes was encouraging.

Data on dry matter yield as calculated from clipped samples harvested from outer slopes on White Oak Mountain in early fall of 1971 and 1972 are given in table 6. The average dry-matter yield in 1971 on the rock phosphate plots was 3,791 lb per acre. This compared very favorably with an average of 4,474 lb per acre on the superphosphate plots (320 lb of P_2O_5). Likewise, the average yield from direct seeding was 3,916 lb per acre and 4,020 lb per acre from the transplanted plots. The average yield in 1972 from rock phosphate was 6,563 lb per acre and from superphosphate 7,020 lb per acre, with similar yields from direct seeding and transplanting. Yield samples were separated to determine the legume-grass ratio. From the seeded plots, birdsfoot trefoil made up 37 percent of the yield as compared with 36 percent from the transplanted plots in 1971. In 1972, estimates indicate a legume increase to 82 percent, from

Figure 16.--Excellent seed germination and early seedling development in terraced grooves.

Figure 17.--Complete vegetative cover of weeping lovegrass and birdsfoot trefoil by late summer of seeding year.

Figure 18.--Growth of weeping lovegrass and crownvetch when amended with superphosphate on an outer slope of Bolt Mountain (pH 2.8). Dolomite, N and K were applied at uniform rates.

Table 6.--Yield data from outer slopes on White Oak Mountain, W. Va.

Phosphorus[1/] treatment	Legume establishment	Dry matter yield (lb per acre) of weeping lovegrass and birdsfoot trefoil	
		1971	1972
2 tons rock phosphate	Seeded	3,445	5,333
	Transplanted	3,998	7,964
3 tons rock phosphate	Seeded	5.677	7,156
	Transplanted	2,311	6,428
4 tons rock phosphate	Seeded	3,446	7,020
	Transplanted	4.518	5,477
320 lb P_2O_5	Seeded	3,094	7,020
	Transplanted	5,853	7,020

1/ Uniform applications of amendments included 50 lb of N, 150 lb of K, 2 tons of dolomite, and 1 lb of Mo per acre.

direct seeding and 72 percent, from transplanting. The extra work and cost involved in transplanting the legumes is not necessary when a good stand of weeping lovegrass and Ky 31 fescue can be developed from seed to protect the legume seedling.

Average yields in 1971 from the more acid spoil at Bolt Mountain were approximately 3,000 lb per acre for both the birdsfoot trefoil and crownvetch seedings (table 7). The legume fraction, however, made up only 18 percent of the vegetation during the seeding year. Yield variations within each fertility treatment for seeded and transplanted plots were strongly associated with the stand and response of the overseeded weeping lovegrass. Average yield differences between rock phosphate and superphosphate treatments were small. In 1972, with birdsfoot trefoil, yield averaged 4,172 lb per acre from rock phosphate and only 3,510 lb per acre from superphosphate. With crownvetch, yields averaged 4,595, and 4,633 lb per acre, respectively. Figure 19 shows the plant growth response to 4 tons of phosphate rock per acre. In the birdsfoot trefoil study the legume increased to 28 percent, from both the direct seeded and transplanted plots, while in the crownvetch study the legume increased to 41 and 50 percent, respectively.

Yield data were not determined after the first two seasons. Normally, no harvest would be made of the vegetative growth on steep outer slopes. The vegetative cover should be left undisturbed to effect spoil stabilization and erosion control. Initial data were taken to evaluate the effectiveness of

Table 7.--Yield data from outer slopes on Bolt Mountain, W. Va.

Phosphorus[1/] treatment	Legume establishment	Dry matter yield (lb per acre) of weeping lovegrass and Birdsfoot trefoil		Crownvetch	
		1971	1972	1971	1972
2 tons rock phosphate	Seeded	3,031	3,846	2,783	3,702
	Transplanted	2,175	3,422	4,525	6,508
4 tons rock phosphate	Seeded	3,534	4,758	3,702	4,545
	Transplanted	2,966	4,653	2,031	4,294
6 tons rock phosphate	Seeded	3,262	4,342	2,455	4,518
	Transplanted	2,111	4,014	2,679	4,094
320 lb of P_2O_5	Seeded	3,510	3,934	3,182	3,174
	Transplanted	1,719	3,286	3,990	6,093

1/ Uniform applications of amendments included, 50 lb per acre of N, 150 lb of K, 5 tons of dolomite and 1 lb of Mo per acre.

Figure 19.--Crownvetch growing on a Bolt Mountain outer slope spoil (pH 2.8) amended with 4 tons per acre of rock phosphate. The experimental area was given uniform applications of N and K.

different spoil amendments on the growth of selected plant species. Thereafter, observations of plant growth were made to determine the longevity of plant stand. The survival of plant stands remained excellent throughout the 1974 season and entered the 1975 season still providing complete ground cover and erosion control.

Potential Use of the Lateral Groove Technique

The terraces constructed on the outer slope face before seeding helped greatly in obtaining a quick plant cover. With the lateral terrace groove technique and possibly the use of a wider range of herbaceous plants, seedlings may be established faster during the height of the growing season. The advantage of improved soil-water relations in the grooves, plus the banding effects of the seed and fertilizer, apparently caused rapid plant establishment for soil stabilization and erosion control.

Construction equipment, such as hydraulic truck cranes or excavator-grading crawlers with telescoping booms, could be modified easily and equipped with a yardarm for making the terraces. With a hydraulic motor, scarifying tools could operate back and forth across the yardarm. To eliminate side draft, the scarifying feet could operate simultaneously from each end of the yardarm and move toward the boom.

A sketch of a proposed lateral groove concept is shown in figure 20. This proposed outer slope seed ledge machine, limiting terraces to the length of the yardarm (16 or 20 feet), would form closed-end basins and would eliminate the need for precise contouring and costly engineering.

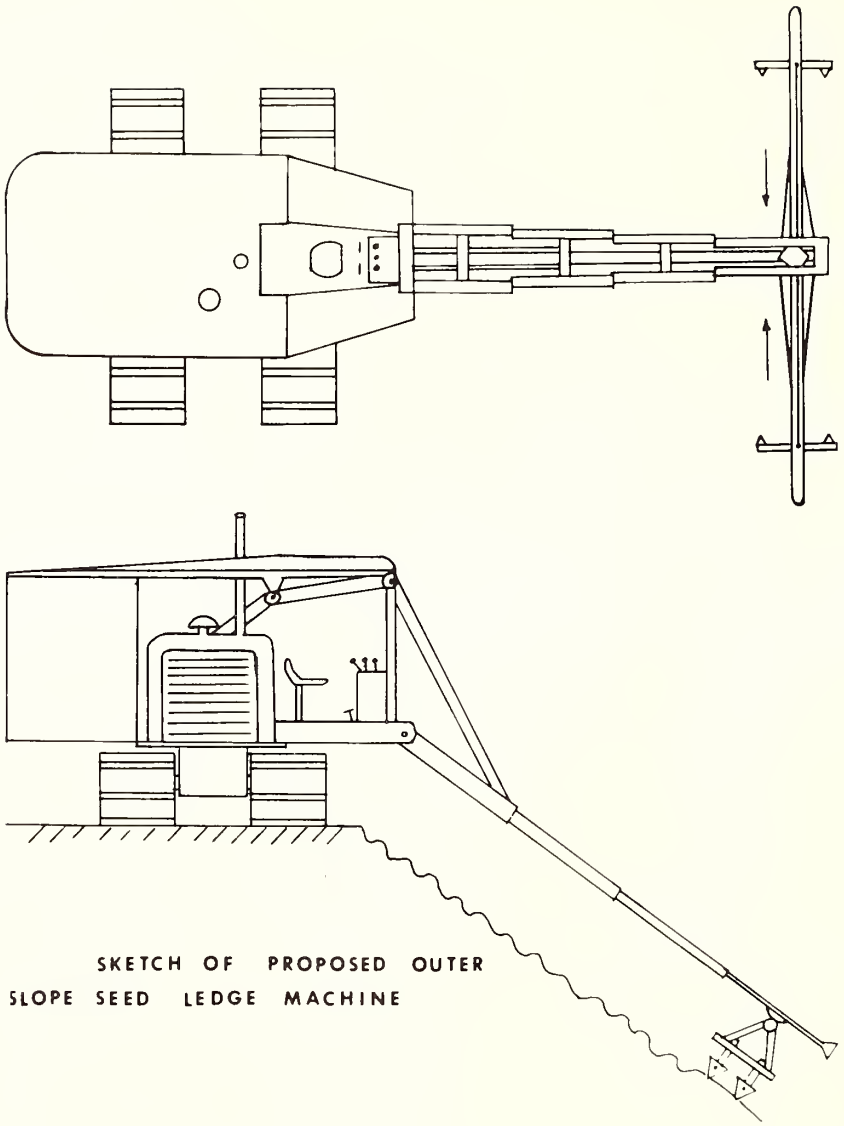

Figure 20.--Drawing of a machine designed by J. N. Jones, Jr., for constructing lateral grooves in strip-mined spoil outer slopes.

Other concepts may be developed to aid seedling establishment on outer slopes, such as the use of annuals or cereal grains to provide a quick ground cover which later serves as an in situ mulch. Germination of cereal grain could be activated by presoaking in water for 12 to 24 hours before using a hydroseeder with the pulp fiber added.

CONCLUSIONS

Uncontrolled erosion and pollution of our streams through siltation and acid drainage from old, abandoned strip-mine sites will continue to be a serious problem unless brought under control. However, areas of this type in Appalachia can be revegetated if the physical and chemical restraints can be identified and corrected through utilizing proper spoil amendments. Also required are plant species which are environmentally adapted for growth in the region. In most instances, mulches are a requisite for seed germination and early seedling development. If spoil neutralization and suitable seeding and mulching techniques are followed, then the reclamation of these disturbed areas can be accomplished by the growth of grasses and legumes. Collective efforts of the strip-mine operators, State and Federal agencies, and land owners are indispensable to expedite the healing of the scars created by man's attempt to supply a much-needed resource for energy production.

LITERATURE CITED

(1) Bennett, O. L. 1971. Revegetation to heal scars. In 23rd Ann. Meeting of the Soil Conserv. Soc. Amer. Proc. pp. 249-253. Hot Springs, Ark. September 30 - October 3, 1970.

(2) Bennett, O. L., Jones, J. N., Jr., Armiger, W. H., and Lundberg, P. E. 1973. New techniques for revegetating strip-mined areas. In 27th Ann. Meeting of the Soil Conserv. Soc. Amer. Proc. pp. 50-55. Portland, Oreg. October 1972.

(3) Clark, L. J. 1969. Mine Drainage in the North Branch Potomac River Basin. Chesapeake Tech. Support Lab., Middle Atlantic Region, Fed. Water Pollut. Control Admin., U.S. Dept. Int., Tech. Report No. 13. 87 pp., illus.

(4) Hughes, H., Heath, M. E., and Metcalfe, D. L. 1966. Forages. Iowa State Univ. Press. 2nd Ed. 706 pp., illus.

(5) Kownaka, M. 1958. [Preliminary observations on zig-zag clover (Trifolium medium L.)] Roczniki Nauk Rolniczych., v. 72 ser. F, No. 3: 1-6. [Translated and published for the Natl. Sci. Found. and the U.S. Dept. Agr. by Centralny Instytut Informacji Naukowo-Technicznej I Ekonomicznej. Warszawa, Poland. 1961].

(6) Keim, W. F. 1954. Status of Trifolium ambiguum as a forage legume. Iowa Acad. Sci. Proc. 61:132-137.

(7) Paone, J., Morning, J. L., and Giorgetti, L. 1974. Land utilization and reclamation in the mining industry, 1930-1971. U.S. Bur. Mines. Inform. Cir. 8642. 55 pp., illus.

(8) Park, W. H., Williams, A. W., and Krumwiede, C. Jr. 1917. Pathogenic Microorganisms. Lea and Febiger. 709 pp., illus. New York and Philadelphia.

(9) Ruffner, J. D., and Hall, J. G. 1963. Crownvetch in West Virginia, West Va. Univ. Agr. Expt. Sta. Bull. 487.

(10) U.S. Department of Interior. 1969. Study of strip and surface mining in Appalachia. In interim report by the Sec. of the Int. to the Appalachian Reg. Comn. 78 pp., illus.

GPO 904-865

U. S. DEPARTMENT OF AGRICULTURE
AGRICULTURAL RESEARCH SERVICE
NORTHEASTERN REGION
AGRICULTURAL RESEARCH CENTER WEST
BELTSVILLE, MARYLAND 20705

OFFICIAL BUSINESS
PENALTY FOR PRIVATE USE, $300

POSTAGE AND FEES PAID
U. S. DEPARTMENT OF
AGRICULTURE
AGR 101